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Termination Report

FLOW IN HYDRAULIC MACHINERY

Hydrodynamics Laboratory
California Institute of Technology
Pasadena, California

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INTRODUCTION

This report concludes the work conducted by the Hydrodynamics Laboratory at the California Institute of Technology under Contract N6onr-244, Task II, in the general field of hydraulic machinery. This work was initiated in January 1947 under the initial guidance of Professors Knapp and Hollander. It has subsequently been continued by additional amendments to the original contract up to the present.

The over-all objectives of this program were to make detailed observations and measurements of the internal flow in rotating impellers and stationary diffusors to permit the establishment of accurate design procedures for hydraulic machinery, and to serve as a starting point for realistic mathematical analysis of such flows.

It is the intention of this report to indicate the scope of the work done under this contract and to describe the facilities built for its experimental end. A further aim is to outline, in brief, the reports and publications issued and some incidental benefits derived from this project.

SCOPE OF WORK AND FACILITIES

The basis of understanding and any analysis of the real fluid flows occurring in rotating turbo-machines rests on experimental work. For this reason it was decided at the very outset to emphasize the experimental approach.

Unlike the original Hydraulic Machinery Laboratory which used complete pumping units and measured as far as the impeller is concerned, only the in- and outflow velocities, pressures and torque, the purpose of this facility, as originally conceived, was mainly to investigate the complete flow picture through centrifugal and axial flow impellers, while permitting other research with only minor changes. Thus the test facility had to be built for maximum flexibility within the limited space available.

Some unique features incorporated in it and some novel experimental techniques used with it are:

(a) Three test stands are located around a square central column. Two of these are provided with a metered flow in either direction.[1, 3] The third stand, originally made for central photography, is now replaced by the self-contained inducer facility.[22] An additional self-contained test stand was also fabricated (with industrial sponsorship) for use with expensive working fluids.

(b) Specially designed, light weight, narrow line blind shut-off valves permit an easy change of the setup and compact arrangement of the piping.

(c) Special throttle valve with long travel for exact setting indicated by counter permit exact repetition of a test.

(d) Rotating water-manometer with up to 32 tubes directly connected by plastic tubing to the small brass tubes in the impeller hub leading to impeller blades. Thus the pressures along the impeller blades can be read very fast stroboscopically.

(e) Stereoscopic photography to observe three-dimensional flows.

(f) Lucite impeller shrouds for centrifugal impellers followed by lucite diffusors and similarly lucite blades and/or case for axial flow units for observation and photography.

The experimental work done falls, roughly, into three categories:

The first consists of over-all and internal flow observation and measurement in centrifugal pump impellers. Numerous different designs were employed all in the range of good efficiency as obtains in conventional pump practice. In the same category, two-dimensional impellers, with parallel shrouds, were also tested because the flows were the subject of comparison with potential flow theory. This project was one of the theses carried through at the laboratory.[7, 11, 19]

Another thesis under this heading was the investigation of different shroud boundaries by electrical analogy.[20]

Using the modified test stand previously mentioned, a series of experiments was made on the effect of Reynolds number. A mixture of glycerine and water was used for this purpose and the work was carried out under industrial sponsorship. This work would not have been possible without the equipment and experience gained under the present contract.

The second category consists of experimental work on axial flow impellers suitable for operation in the pump rather than in the compressor field.[8, 9, 10, 17]

Theoretical considerations led to a new design procedure for axial flow pumps and the experimental work was conducted to substantiate the theory.

The third category and the most recent area is an experimental investigation of cavitation. This work is being carried out with axial flow inducers. These are impellers designed to operate in the cavitating regime and their function is to supply the subsequent pumping stage with a pressurized stream of bubble-free liquid. The investigation of this problem is only in the preliminary stage, though some results are available.[22] As with the other categories, some analytical studies have been, and are being, undertaken to interpret and clarify the experimental results.

The emphasis and direction of the work of the project as such has been described. However, the presence of this equipment and the project staff have provided opportunity and stimulus for additional research. As an example may be cited the complete pumping characteristic (Karman-Knapp) diagram for axial and mixed flow pumps[18] previously only available for centrifugal machines.

Furthermore, as part of an educational institution with strong connections to Industry, this program made a real contribution by employing research engineers lent by industry, as well as graduate and undergraduate students, to make them familiar with experimental techniques and give scope to and develop their initiative to new approaches. The five theses attest the effectiveness of this effort. Those graduated from this program are today heading or conducting research in these fields.

LIST OF PUBLICATIONS AND REPORTS

In this section the various technical reports and publications issued under this contract are listed. The titles usually are self-explanatory. Where they are not, a brief explanation is added. At the end of this list, various graduate theses done under the project, or with the use of the contract facilities, are reported.

Item	Title
1.	Laboratory Developments for Study of Flow in Rotating Channels, Knapp, R.T., Hollander, A., Acosta, A.J., Osborne, W.C., presented before Annual Meeting ASME, Nov. 28, 1948.
2.	Design of Ship Propellers, Morelli, D.A., presented before Society of Naval Architects and Marine Engineers, Northern California Section, Nov. 1949.
3.	Head and Flow Observations on a High Efficiency Centrifugal Pump Impeller, Osborne, W.C., Morelli, D.A., Trans. ASME, Oct. 1950, Hydrodynamics Laboratory Publication No. 80.
4.	Measured Performance of Pump Impellers, Osborne, W.C., Morelli, D.A., Hydrodynamics Laboratory Publication No. 88, ASME preprint 50-A-90, Jan. 1950.
5.	Evaluation of a Two-Dimensional Centrifugal Pump Impeller, Beveridge, J.H., Morelli, D.A., Hydrodynamics Laboratory Publication No. 90, ASME Preprint 50-A-147, Jan. 1951.
6.	Pressure Distribution on the Vanes of a Radial Flow Impeller, Morelli, D.A., Hydrodynamics Laboratory Publication No. 97, June, 1951. Also published in Heat Transfer and Fluid Mechanics Institute 1951, p. 73, Stanford University Press, Stanford, Calif.
7.	An Experimental and Theoretical Investigation of Two-Dimensional Centrifugal Pump Impellers, Acosta, A.J., Hydrodynamics Laboratory Report No. 21-9, June 1952. Also published in Trans. ASME, Vol. 76, p. 749, 1954.

8. Three-Dimensional Interference Effects of a Finite Number of Blades in an Axial Turbomachine, Tyson, H., Hydrodynamics Laboratory Report No. E-19.1, Nov. 1952.

9. Pressure Distributions on the Blade of an Axial Flow Propeller Pump, Morelli, D.A., Bowerman, R.D., Hydrodynamics Laboratory Report No. E-19.2, Nov. 1952. Also published in Trans. ASME, Vol. 75, Aug. 1953.

10. An Experimental Study of Axial Flow Pump Cavitation, Guinard, P., Fuller, T., Acosta, A.J., Hydrodynamics Laboratory Report No. E-19.3, Sept. 1953.

11. Potential Flow through Radial Flow Turbomachine Rotors, Acosta, A.J., Hydrodynamics Laboratory Report No. E-19.4, Feb. 1954.

12. Note on the Effect of Meridian Curvature, Acosta, A.J., Hydrodynamics Laboratory Report No. E-19.5, April 1954. An analytical study of the effect of meridian curvature on the performance of mixed flow impellers.

13. Experimental Study of Flow between Centrifugal Pump Impeller Shrouds, Tyson, H.N., Hydrodynamics Laboratory Report No. E-19.6, July 1954.

14. Effect of the Volute on Performance of a Centrifugal Pump Impeller, Bowerman, R.D., Hydrodynamics Laboratory Report No. E-19.7, March 1955. Also ASME preprint 56-5A-45, July 1956.

15. An Experimental Study of Centrifugal Pump Impellers, Acosta, A.J., Bowerman, R.D., Hydrodynamics Laboratory Report No. E-19.8, Aug. 1955. To be published in Transactions ASME.

16. Note on Partial Cavitation of Flat Plate Hydrofoils, Acosta, A.J., Hydrodynamics Laboratory Report No. E-19.9, Oct. 1955. Also presented before American Physical Society, Div. of Fluid Mechanics, California Institute of Technology, March 1956.

17. Design of Axial Flow Pumps, Bowerman, R.D., ASME Paper No. 55-A-127, Nov. 1955, Hydrodynamics Laboratory Report No. E-19.10 (to be issued).

18.* Complete Characteristic Circle Diagrams for Turbomachinery, Thesis for Mechanical Engineer by W. M. Swanson, California Institute of Technology, 1951. An experimental investigation of axial and mixed flow pumps in the pumping, turbining, and power dissipation regimes.

19.* An Experimental and Theoretical Investigation of Two-Dimensional Centrifugal Pump Impellers, Thesis for Doctor of Philosophy by A. J. Acosta, California Institute of Technology, 1952.

20.* Investigations of Boundaries for Transitions from Axial to Two-Dimensional Flow by Electrical Analogy, Thesis for Mechanical Engineer by Marc Kampe de Fériet, California Institute of Technology, 1953.

21.* Investigation of a Three-Dimensional Design Procedure for Axial Flow Pump Impellers, Thesis for Mechanical Engineer by Ray D. Bowerman, California Institute of Technology, 1955.

22.* Cavitation Studies in Axial Inducers, Thesis for Aeronautical Engineer by Henry John Nawoj, California Institute of Technology, 1956.

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